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## SINGLE-CYLINDER OIL-CONTROL TESTS OF POROUS CHROME-PLATED CYLINDER BARRELS FOR RADIAL AIR-COOLED ENGINES

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# SINGLE-CYLINDER OIL-CONTROL TESTS OF POROUS CHROME-PLATED CYLINDER BARRELS FOR RADIAL AIR-COOLED ENGINES

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## SUMMARY

A series of single-cylinder engine tests was run to determine a satisfactory method of reducing oil consumption in radial air-cooled engines with flat-face compression rings as standard parts and equipped with cylinder barrels salvaged by porous chrome plating.

Tests were conducted using porous chrome-plated cylinders having straight and choke bores with standard flat-face compression rings. These tests were compared with additional tests employing previously used straight-bore porous chrome-plated cylinder barrels with various piston-ring assemblies, including assemblies with taper-face compression rings.

The oil consumption was reduced by more than one-half in the tests using the piston assembly with three $1^{\circ}$ taper-face compression rings. Slight increases in blow-by accompanied the use of taper-face compression rings but no deleterious effects were observed.

The tests reported herein indicate that, when a choke was incorporated in a cylinder, the oil consumption was reduced one-third or more without any apparent undesirable effect on engine performance. The initial oil consumption was appreciably higher in the tests employing previously used cylinders than in the tests using cylinders with a honed finish when tested with the same ring assembly.

A heavy bearing area was noted on the top edge of the top compression ring after all the tests in which a piston-ring assembly having a top flat-face compression ring was used, which indicates that the rings were scraping oil into the combustion chamber.

## INTRODUCTION

Previous testing by the NACA indicated that the use of chrome-plated cylinder barrels in radial air-cooled engines having flat-face compression rings as standard parts results in high specific oil consumption. Tests reported in reference 1 show that the specific oil consumption can be reduced by using special surface coatings in porous chrome-plated cylinder barrels.

The data presented herein were obtained from seven tests conducted early in 1944 at the NACA Cleveland laboratory. The purpose of these tests was to determine a means of reducing specific oil consumption and thereby to arrive at a satisfactory method of adapting porous chrome-plated cylinder barrels to radial air-cooled engines. The adaptation would provide a simple means of salvaging cylinder barrels worn oversize in service and thus greatly reduce the spare-parts requirements. It was considered essential that the method be such that the difficulty of high oil consumption would be obviated without incurring a complex assembly change or causing undesirable engine operating characteristics.

In tests 1 to 4, choke-bore and straight-bore porous chrome-plated cylinders with standard piston-ring assemblies were tested in unused cylinders to determine the effect of choke contour on specific oil consumption. Standard and taper-face compression rings were tested in previously used straight-bore cylinders in tests 5, 6, and 7.

## APPARATUS AND TEST PROCEDURE

Four front-row cylinders from a radial air-cooled engine were tested on an NACA universal test engine crankcase. The bore of these cylinders is $5\frac{1}{2}$ inches and the stroke used was $5\frac{1}{2}$ inches. The compression ratio for these tests was 6.7.

Straight-bore chrome-plated cylinders were used in tests 1 and 2. These cylinders were plated in June 1943 according to the best methods available for porous chrome plating. Used cylinders were prepared for plating by grinding or honing the barrels 0.015 to 0.025 inch oversize producing a straight bore with a surface roughness of approximately 10 rms. Surfaces not to be plated were protected from the plating bath with wax and lacquer and the cylinders were assembled with the necessary anode and plating fixtures. The cylinders were cleaned by degreasing and electrolytic pretreating (anodic etching) in a chromic-acid solution for 15 minutes at a current density of 2 amperes per square inch of surface. Plating was accomplished in a bath having 250 grams of chromic acid per liter of solution with a weight ratio of chromic acid to sulfate radical of 100:1. A current

density of 3 amperes per square inch was used for plating and the solution was maintained at a temperature of 140° F. The cylinder was plated to slightly less than nominal diameter and post-treated by anodic etching for 10 minutes with a current density of 2.5 amperes per square inch. The cylinders were rough-honed with B-320 B-12 stones and finished-honed to size and porosity with B-600 B-10 stones using the cross-hatch method of honing. The cylinder barrels were cleaned with a manually directed spray nozzle using trichloroethylene and compressed air under 100 pounds per square inch gage pressure.

Tests 3 and 4 were run with porous chrome-plated cylinders that incorporate a choke as illustrated by figure 1. The plating methods used for preparing these cylinders were essentially the same as those adhered to in June 1943, which are described in the preceding paragraph, except for better control of plating conditions. A special anode was used that caused a choke to be formed in the cylinder barrel during plating. The anode used for plating these cylinders (fig. 2) had the diameter increased on a taper in the location where, during plating, it will affect a choke as desired in the cylinder. When the clearance between the anode and the cathode (cylinder barrel) is decreased, an increased rate of plate deposition results to form the choke contour. The cylinders were cleaned in the same manner as in tests 1 and 2 except a mechanically directed spray nozzle was used to cover repeatedly the cylinder bore.

The cylinder used in test 2 was again used in test 5 and the cylinder used in test 1 was used in test 6. Neither bore surface was refinished nor sufficiently cleaned to remove any engine deposits. Test 7 was run using the cylinder that had been previously used in tests 2 and 5.

The cylinders used in these tests were examined and photographed at a magnification of 108 diameters before and after testing by an internal-surface projector. The optical system of this instrument, as shown in figure 3, is fixed and the cylinder under inspection is positioned with regard to the objective lens. The cylinder is fitted to an adapter mounted by pins on a table that can be raised, lowered, and rotated by small electric motors controlled by microswitches. The instrument is so designed that any area in a cylinder barrel can be located in a few seconds. The vertical and circumferential positions of the cylinder adapter are so indexed by scales that a given surface area can be inspected and photographed before and after testing. Focusing is accomplished by a hand-operated screw that moves the surface under inspection with respect to the objective projecting mirror.

Cylinder-bore diameters were measured before and after each test with a three-point dial-type indicator. A standard ring gage

of nominal cylinder-bore diameter was used in setting the dial-type indicator at zero. The chrome-plated surfaces were inspected with respect to porosity, plateau finish, and general surface appearance before and after test by the internal-surface projector.

The piston and rings used in tests 1, 2, 3, 4, and 7 constitute the standard assembly for this series of tests and include flat-face, cast-iron compression rings. In test 5 the top compression ring was a standard cast-iron ring altered by the manufacturer to have a $1^\circ$ taper face and was installed to scrape down. The piston and other five rings were standard parts. In test 6 all the compression rings were standard cast-iron rings altered by the manufacturer to have a $1^\circ$ taper face and were installed to scrape down. The bottom three rings were standard parts. The standard rings in all tests were lapped without rotation in a dummy barrel using Clover 2-A lapping compound until the compression rings showed full-face contact. None of the $1^\circ$ taper-face rings were lapped.

The piston rings were inspected for light-tightness as specified in SAE Aeronautical Material Specification 7310. Measurements were made of free gap, compressed gap, oil-ring-bearing face width, and diametral tension before and after test. Compressed gap was measured in a standard ring gage of nominal diameter and ring-face width was determined with a calibrated microscope. The rings were weighed before and after test on an analytical balance. Diametral tension was measured by determining the force applied on a diameter $90^\circ$ from the gap that was necessary to close the ring to its installation compressed gap.

Unit wall pressure was computed for the oil-control rings using the following formula obtained from reference 2:

$$\text{Unit pressure} = \frac{0.76 \times \text{diametral tension}}{\text{nominal ring diameter} \times \text{contacting face width}}$$

The unit pressure obtained is a mean bearing pressure for the ring and is not to be considered the true bearing pressure at all points on the circumference of the ring.

The fuel, AN-F-28, Amendment-2, was supplied to the intake pipe at a constant rate through a manifold injection nozzle and fuel flow was measured by a calibrated rotameter.

Lubricating oil, Navy Symbol No. 1120, was supplied to the piston and cylinder by means of crankshaft throw-off and four auxiliary oil jets; two jets were directed at the under side of the piston and two jets were directed at the barrel surface. The four

jets had a total flow rate of approximately 5 pounds per minute. The oil consumption and flow were measured by the device described in reference 3.

The power output was absorbed and measured by a cradled electric dynamometer. The blow-by rate was determined by a positive-displacement gas meter. The crankcase pressure was manually maintained at 1/2 inch of water vacuum in order that leakage into the crankcase remained constant.

Cylinder cooling air was obtained from the laboratory central blower system. Standard flight cooling-air deflectors were installed on the cylinders. Combustion air was supplied by a blower and air flow was measured with a sharp-edge thin-plate orifice installed according to A.S.M.E. standards.

Each of the seven tests was operated for a total running time of 10 hours under the following conditions:

| | |
|---|---|
| Engine speed, rpm | 2400 |
| Brake mean effective pressure, pounds per square inch | 192 |
| Brake horsepower | 76 |
| Spark timing, degrees B.T.C. | 25 |
| Fuel-air ratio | 0.095 |
| Rear-spark-plug-bushing temperature, °F | 420 |
| Temperature at center of barrel downstream, °F | 325 |
| Oil-in temperature, °F | 180 |
| Oil flow from four cylinder jets, pounds per minute | 5 |

The conditions and schedule under which the piston rings were run-in for all tests are given in table 1. Table 2 presents the combinations of cylinder bore and rings tested together.

## RESULTS AND DISCUSSION

Several manufacturers of air-cooled aircraft engines incorporate choke contour such as shown in figure 1 in the cylinder bores. The data included in this report show that incorporating a choke bore in cylinders effects a very appreciable reduction in specific oil consumption for engines equipped with porous chrome-plated cylinder barrels. It is shown by figure 26 of reference 4 that in operation the choke-bore cylinder is approximately straight. This condition is caused by expansion variations resulting from the very large axial temperature gradient and the thermal distortion characteristics of the head and barrel assembly. It is therefore obvious that the straight-bore cylinders will be of greater diameter at the top of the barrel than at the bottom during operation. The condition encountered in

straight-bore cylinders during operation, consequently, causes excessive piston clearance and ring back clearance, which results in the poor functioning of the component parts of the assembly and leads to undesirable engine performance characteristics.

The test results given in table 2 show the extent of the reduction in oil consumption obtained for the single cylinder by the use of choke-plated cylinder barrels. Comparison of the mean values for tests 1 and 2 with those for tests 3 and 4 indicates that the oil consumption would be reduced more than one-third when choke bores were used instead of straight bores in air-cooled chrome-plated cylinder barrels. Figure 4 presents a graphic log of oil consumption during the comparable tests (tests 1, 2, 3, and 4) of straight-bore and choke-bore cylinder barrels with standard rings and clearly illustrates the reduction of oil consumption obtained by use of choke. The effect of taper-face compression rings on oil consumption in tests 5, 6, and 7 is shown in figure 5.

The ring wear was not excessive (fig. 6) but inspection of the top compression rings from tests 1, 2, 3, 4, and 7 revealed that these flat-face compression rings showed heavy bearing on the upper edge of the faces as the rings from test 3 shown in figure 7. This condition would indicate that the rings were scraping oil upward into the combustion chamber, thus contributing to the high oil consumption. It was thought that taper-face compression rings installed to scrape down might overcome this difficulty and also provide additional oil control. Table 2 shows the results of tests using taper-face compression rings.

The results of test 5 are also given in table 2. A marked decrease in oil consumption compared with that obtained in similar tests with flat-face compression rings resulted when taper-face compression rings were used. The oil consumption in test 6 was considerably less than half that observed in test 7. The average specific oil consumption for tests 5, 6, and 7 were 0.010, 0.006, and 0.019 pound per brake horsepower-hour, respectively. The effect of taper-face compression rings on oil consumption is illustrated in figure 5. Test 7 should be used as the base test for comparison of specific-oil-consumption values for tests of flat-face and taper-face compression rings because tests 5 and 6 were also run with previously used chrome-plated straight-bore cylinders. It is indicated from the results of tests 5, 6, and 7 that, with flat-face compression rings, previously used cylinders require longer run-in time to stabilize oil consumption than do unused porous chrome-plated cylinders having a honed finish.

The results of test 7 show that the reduction in oil consumption obtained in tests of taper-face compression rings was not due to the

accumulation of engine deposits in the pores of the chrome plate. It has been shown (reference 1) that, when the pores are effectively filled, a reduction in oil consumption will result. Examination of the cylinder used for tests 2, 5, and 7, however, revealed that the engine deposits, which had accumulated during the total $52\frac{1}{2}$ hours' operating time, were not sufficient to fill the pores to any appreciable extent.

Choke-bore cylinders generally showed a lower blow-by rate than straight-bore cylinders using the same type of ring assembly. It was also noticeable that the blow-by increased with the use of taper-face compression rings. In the data presented in table 2, there is no correlation between oil consumption and blow-by. The blow-by data indicate, however, that there may be a correlation between the geometric relation of the barrel contour and the ring face at operating temperatures and the ability of the assembly to control blow-by. Because of the limitations of blow-by measuring equipment (accuracy, ±10 percent), these indications are not to be considered conclusive.

Ring-weight-loss data for all tests are included in table 2 and are graphically compared in figure 6. The differences in ring wear between tests of straight-bore (tests 1 and 2) and choke-bore (tests 3 and 4) porous chrome-plated cylinder barrels are thought to be mainly the result of improved plating techniques, honing practices, and pore-cleaning methods used in processing the choke-bore cylinder barrels. Robert Insley in a paper presented before an SAE meeting in Detroit in 1936 pointed out that the geometry of the surfaces at operating temperatures might have an appreciable effect on ring wear. In all tests, there were light deposits of lacquer or varnish or both on the chrome plateaus. These deposits are indicative of a compatible surface condition that is conducive to low wear.

After all the tests, the rings were in good condition and compared very favorably with rings that had been run in standard chrome-molybdenum steel cylinder barrels. In general, the surfaces of the rings had a lapped appearance. This surface condition can be seen in figures 7 to 10. It should also be noted that the top ring in figure 10 shows heavy bearing on the upper edge similar to the condition shown in figure 7. This bearing area was probably caused by mechanical distortion of the rings. After the tests with unused barrels, the pistons had running marks on the cross heads as evidence of abrasive material remaining in the pores after cleaning. The pistons that were tested in previously used barrels did not exhibit this characteristic to such a marked extent. Examination and comparison of figures 11 and 12 show the condition mentioned. The pistons from tests 1, 3, and 4 were in very nearly the same condition

as that shown in figure 11 and the pistons from tests 5 and 6 appeared very nearly the same as that shown in figure 12.

The wear of the chrome-plated cylinder bores was so slight that it could not be measured with dial-type gages that are accurate to 0.0002 inch. Examination of the cylinder bores at the ring steps (critical wear area) using the internal-surface projector revealed little or no change in pore characteristics. This fact would again indicate that barrel wear was very slight; if wear had been appreciable, it would have been shown by the decreased width of pores in the wear area at the top of ring travel. Figure 13 is a photomicrograph showing a wear condition as bad as any noted in the barrels used in these tests. This figure shows little change in pore characteristics. Inspection of the cylinders showed them to be in excellent condition with no evidence of surface breakdown, scuffing, or scoring. Figure 14 consists of photomicrographs of the same representative area in a cylinder before and after test 4 Figure 15 is a photograph of a representative cylinder bore after test.

This series of tests shows that choke is a desirable feature in chrome-plated cylinder barrels. Production difficulties arise from the fact that anode clearance is introduced as a process variable. Because of this variable, anode taper must be determined for each plate thickness desired in order to control the difference in the rate of plating in the choke and in the rest of the barrel.

It was noted that some taper-face compression rings also showed slight bearing on the top edge of the face after test. Although the use of taper-face rings compensates for the effect of ring distortion on oil control, it is thought that flat-face compression rings are more desirable than taper-face compression rings because of blow-by control and load-carrying capacity. With keystone-type rings, load-carrying capacity is an important consideration because of the thrust loading of the piston, some of which is taken through the inclined flanks of the rings.

Taper-face compression rings have been found to be a very effective means of lowering specific oil consumption in engines equipped with straight-bore porous chrome-plated cylinder barrels without any accompanying harmful results. This usage offers a practical means of immediately solving the problem of high specific oil consumption without a complex change in engine assembly. It should be noted, however, that taper-face compression rings have not been tested for prolonged periods of time nor under conditions of dusty intake air and high power and therefore performance under those conditions cannot be predicted.

## SUMMARY OF RESULTS

Analysis of the data from these single-cylinder engine tests of air-cooled porous chrome-plated cylinders, which were run at an engine speed of 2400 rpm and with a brake mean effective pressure of 192 pounds per square inch, indicates that the important results can be summarized as follows:

1. The most simple, positive, and expeditious means of lowering initial oil consumption on radial air-cooled engines equipped with straight-bore porous chrome-plated cylinder barrels was to install $1^\circ$ taper-face compression rings so as to scrape down in the top three piston grooves. The oil consumption was reduced more than one-half when this assembly was used. It should be noted that this assembly has not been tested for prolonged periods of time.

2. Blow-by increased slightly with the use of $1^\circ$ taper-face compression rings. At the conditions of these tests, this increased blow-by was not sufficient to have any apparent deleterious effect.

3. The use of choke in porous chrome-plated cylinder barrels for radial air-cooled engines is desirable with regard to reduction of oil consumption. Production difficulty may be a reason why this feature cannot practically be incorporated in porous chrome-plated cylinder barrels. Oil consumption can be reduced at least one-third through the use of choke bores.

4. In all tests in which a flat-face compression ring was used in the top groove, that ring showed heavy bearing area on the upper edge of the ring, which indicated that these rings were scraping oil into the combustion chamber. It is probable that this condition was caused by mechanical distortion of the rings.

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TABLE 1. - RUN-IN CONDITIONS AND SCHEDULE

[Oil, Navy Symbol No. 1120; fuel, AN-F-28, Amendment-2; spark timing, 25° B.T.C.; fuel-air ratio, 0.095; maximum temperatures: rear spark-plug bushing, 420° F; center of barrel, downstream, 325° F; oil-in temperature, 180° F; oil flow from four cylinder jets, 5 lb/min]

| Period | Run-in time (min) | Engine speed (rpm) | Brake mean effective pressure (lb/sq in.) | Brake horse-power |
|---|---|---|---|---|
| 1 | 60 | 1200 | 48 | 10 |
| 2 | 60 | 1300 | 56 | 12 |
| 3 | 30 | 1400 | 68 | 15 |
| 4 | 30 | 1600 | 85 | 23 |
| 5 | 30 | 1800 | 109 | 32 |
| 6 | 60 | 2000 | 135 | 44 |
| 7 | 135 | 2200 | 162 | 59 |
| 8 | 30 | 2300 | 178 | 67 |
| 9 | 10 | 2400 | 192 | 76 |
| | Total 7 hr, 25 min | | | |

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TABLE 2. - SINGLE-CYLINDER OIL-CONTROL TESTS OF POROUS CHROME-PLATED CYLINDER BARRELS

FOR RADIAL AIR-COOLED ENGINES

[Oil, Navy Symbol No. 1120; fuel, AN-F-28, Amendment-2; spark timing, 25° B.T.C.; engine speed, 2400 rpm; brake mean effective pressure, 192 lb/sq in.; fuel-air ratio, 0.095; maximum temperatures: rear spark-plug bushing, 420° F; center of barrel, downstream, 325° F; oil-in temperature, 180° F. Four cylinder jets delivering approximately 5 lb of oil per min.]

| Test variables / Test results | Straight-bore cylinder standard rings (a) | | Choke-bore cylinder standard rings (a) | | Straight-bore previously used cylinders | | |
|---|---|---|---|---|---|---|---|
| | | | | | Taper-face compression ring in top piston groove | Three taper-face compression rings | Standard rings (a) |
| Test number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| NACA reference test number | 2 | 8 | 4 | 5 | 11 | 15 | 13 |
| Duration of test, hr | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Crankcase oil flow, lb/min | 20 | 22 | 21 | 21 | -------------- | 22 | 23 |
| Mean specific oil consumption, lb/bhp-hr | 0.016 | 0.013 | 0.008 | 0.009 | 0.010 | 0.006 | 0.019 |
| Average blow-by (uncorrected), cu ft/min | 0.8 | 0.8 | 0.55 | 0.7 | 0.9 | 1.1 | 0.7 |
| Ring weight loss, gram (a): | | | | | | | |
| 1 | 0.087 | 0.101 | 0.074 | 0.088 | [b]0.035 | [b]0.072 | 0.073 |
| 2 | 0.076 | 0.106 | 0.054 | 0.062 | 0.033 | [b]0.089 | 0.056 |
| 3 | 0.059 | 0.085 | 0.043 | 0.048 | 0.017 | [b]0.039 | 0.036 |
| 4 | 0.049 | 0.060 | 0.036 | 0.039 | 0.011 | 0.030 | 0.025 |
| 5 | 0.043 | 0.054 | 0.030 | 0.043 | 0.016 | 0.022 | 0.028 |
| 6 | 0.042 | 0.041 | 0.023 | 0.025 | 0.013 | 0.018 | 0.013 |
| Total compression-ring weight loss, gram | 0.222 | 0.292 | 0.171 | 0.198 | 0.085 | 0.200 | 0.165 |
| Total oil-ring weight loss, gram | 0.134 | 0.155 | 0.089 | 0.107 | 0.040 | 0.070 | 0.066 |
| Total ring weight loss, gram | 0.356 | 0.447 | 0.260 | 0.305 | 0.125 | 0.270 | 0.231 |
| Initial unit wall pressure for oil rings, lb/sq in.: | | | | | | | |
| Ring 4 | 28 | 24 | 29 | 36 | 40 | 43 | 36 |
| Ring 5 | 36 | 22 | 26 | 28 | 34 | 37 | 27 |
| Ring 6 | 40 | 28 | 28 | 39 | 32 | 29 | 33 |
| Average | 35 | 25 | 28 | 34 | 35 | 36 | 32 |

[a]Standard ring assembly includes flat-face compression rings.
[b]Compression ring altered by manufacturers to have 1° taper face.

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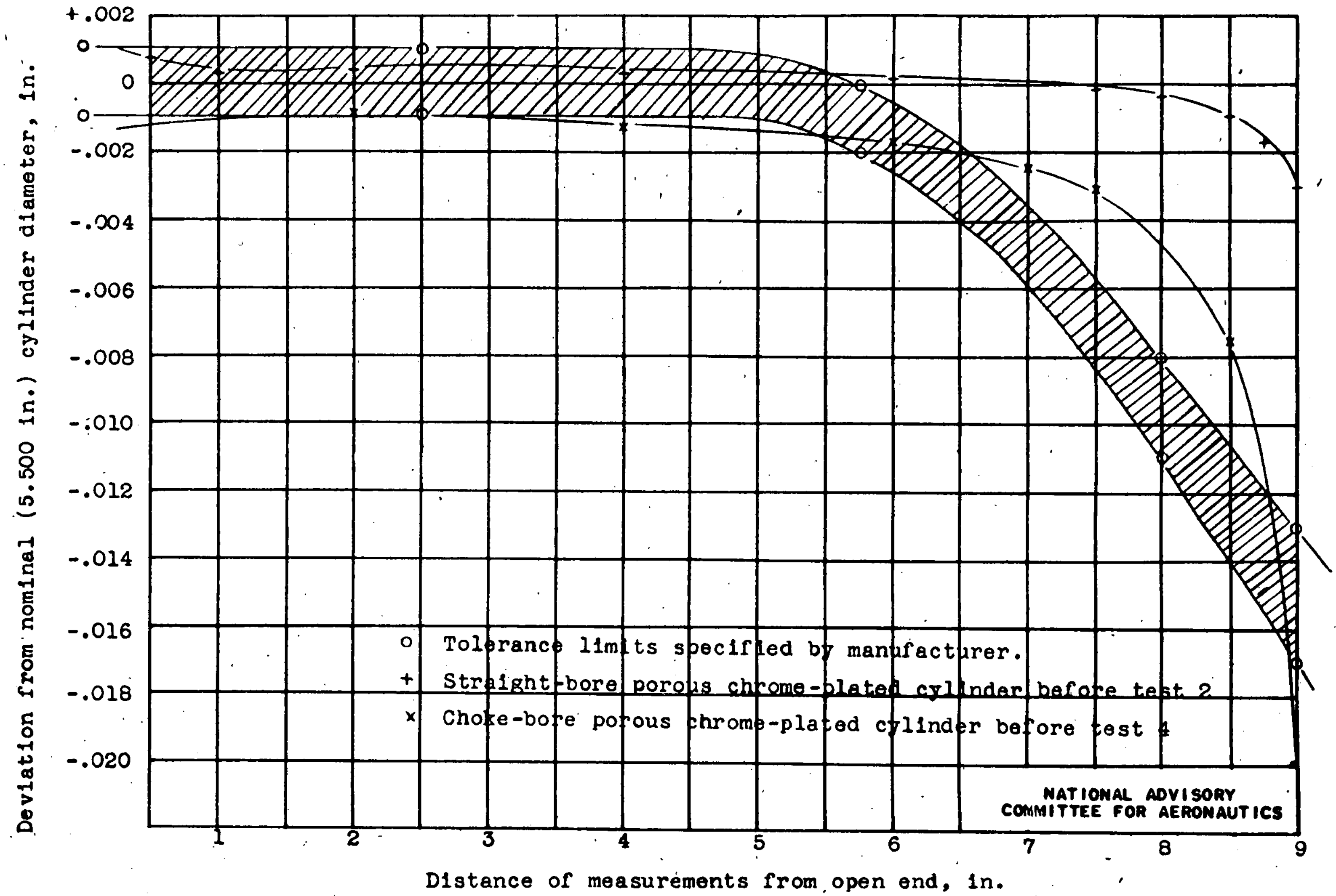


Figure 1. - Air-cooled cylinder contours showing average measurements of thrust and non-thrust diameters taken with three-point dial-type cylinder gage. Total length of barrel, $9\frac{3}{16}$ inches.

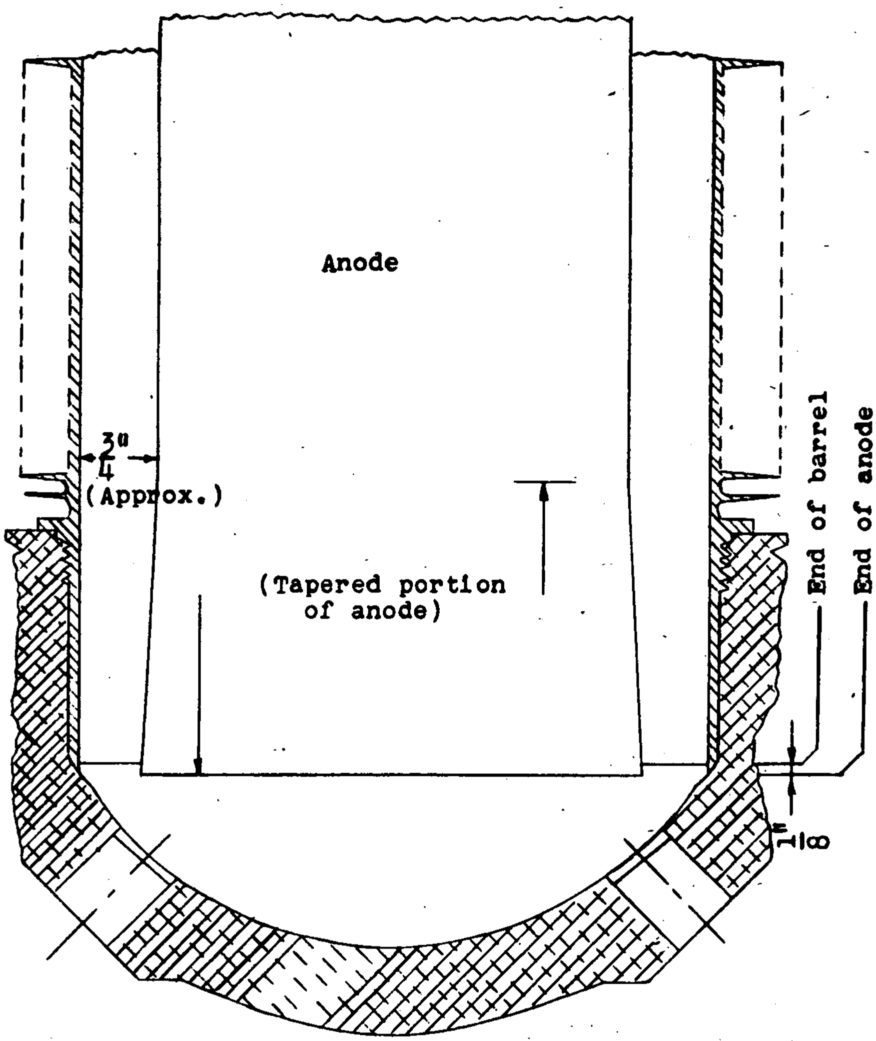


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Figure 2. - Assembly of anode and aircraft-engine cylinder for chrome-plating a choke in the bore. Choke is obtained by decreasing the clearance between the anode and the cylinder barrel (cathode). Taper on anode is determined by desired plate thickness and contour specified.

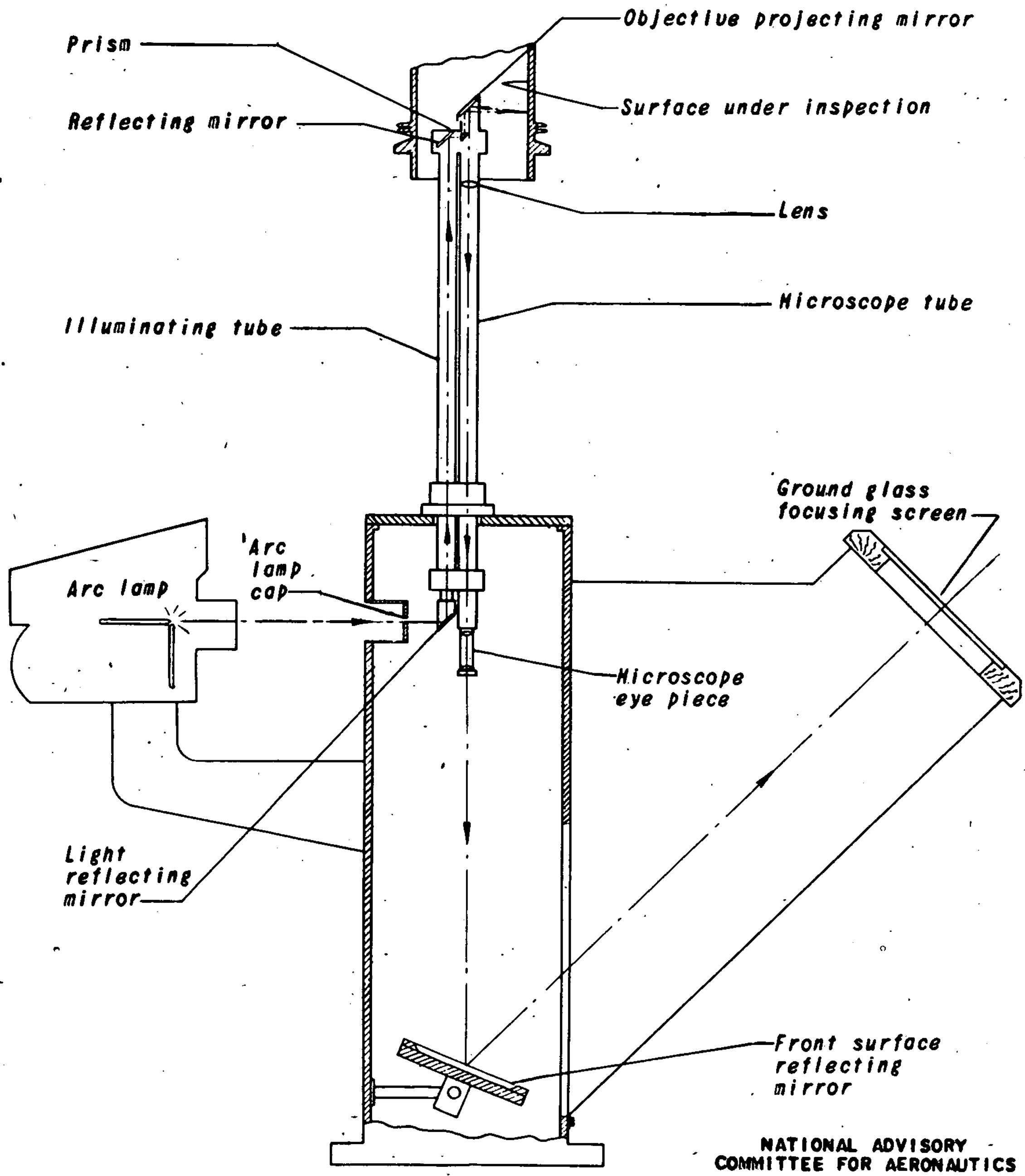


*Figure 3. - Optical system of the internal-surface projector.*

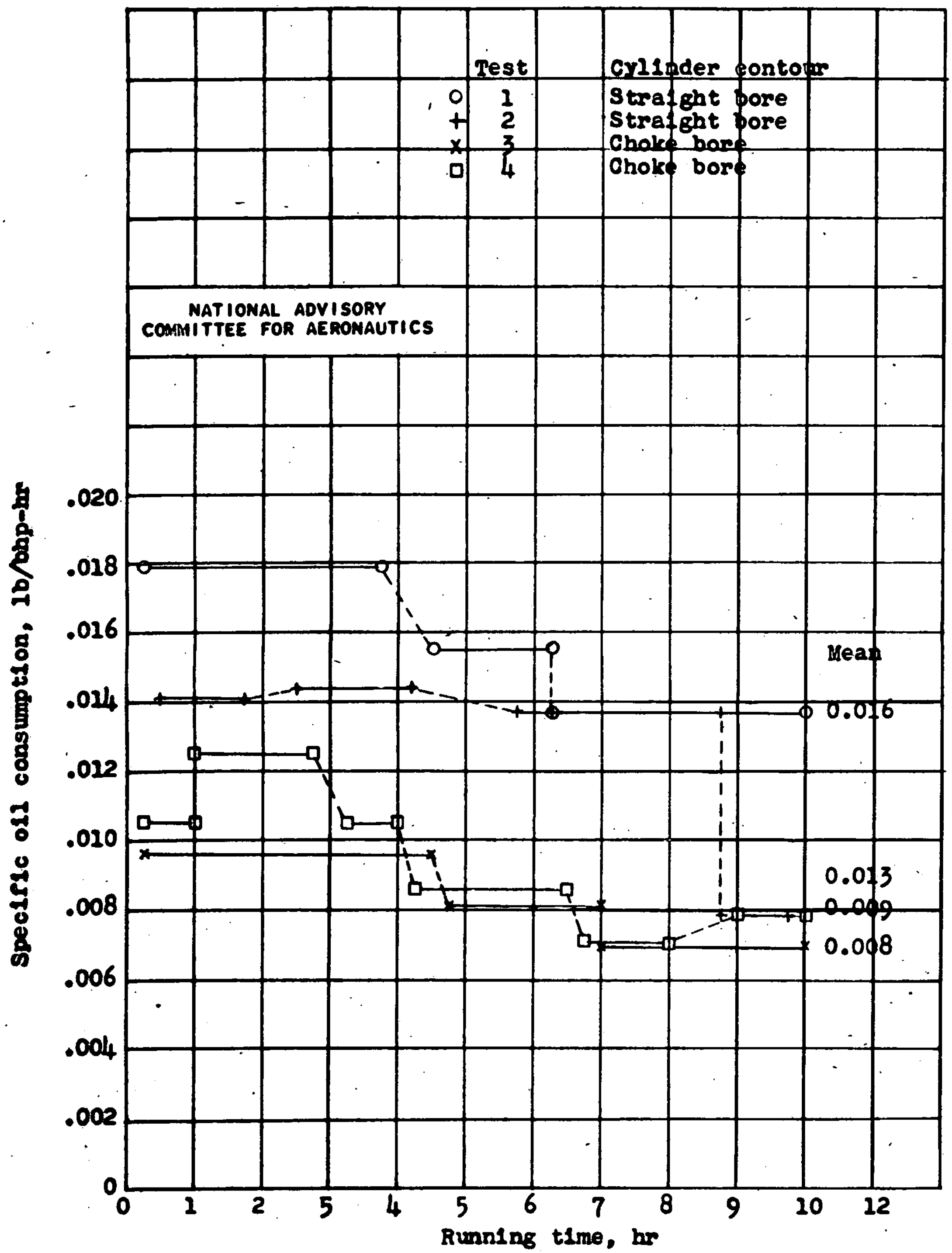


Figure 4. - Specific oil consumption for tests 1, 2, 3, and 4 of straight-bore and choke-bore porous chrome-plated cylinder barrels with standard rings. Engine speed, 2400 rpm; brake mean effective pressure, 192 pounds per square inch.

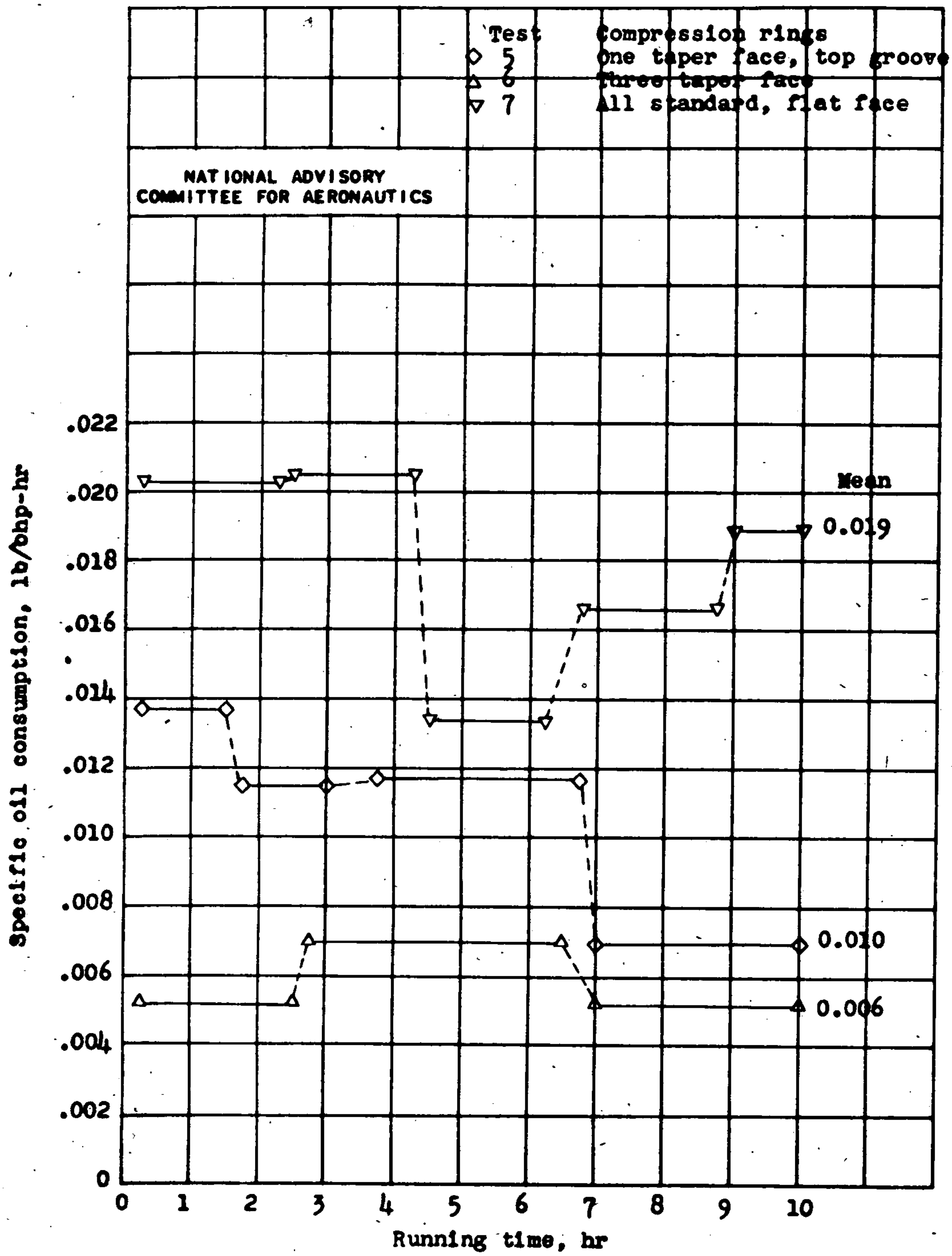


Figure 5. - Specific oil consumption for tests 5, 6, and 7 of previously used straight-bore porous chrome-plated cylinder barrels with taper-face and standard compression rings. Engine speed, 2400 rpm; brake mean effective pressure, 192 pounds per square inch.

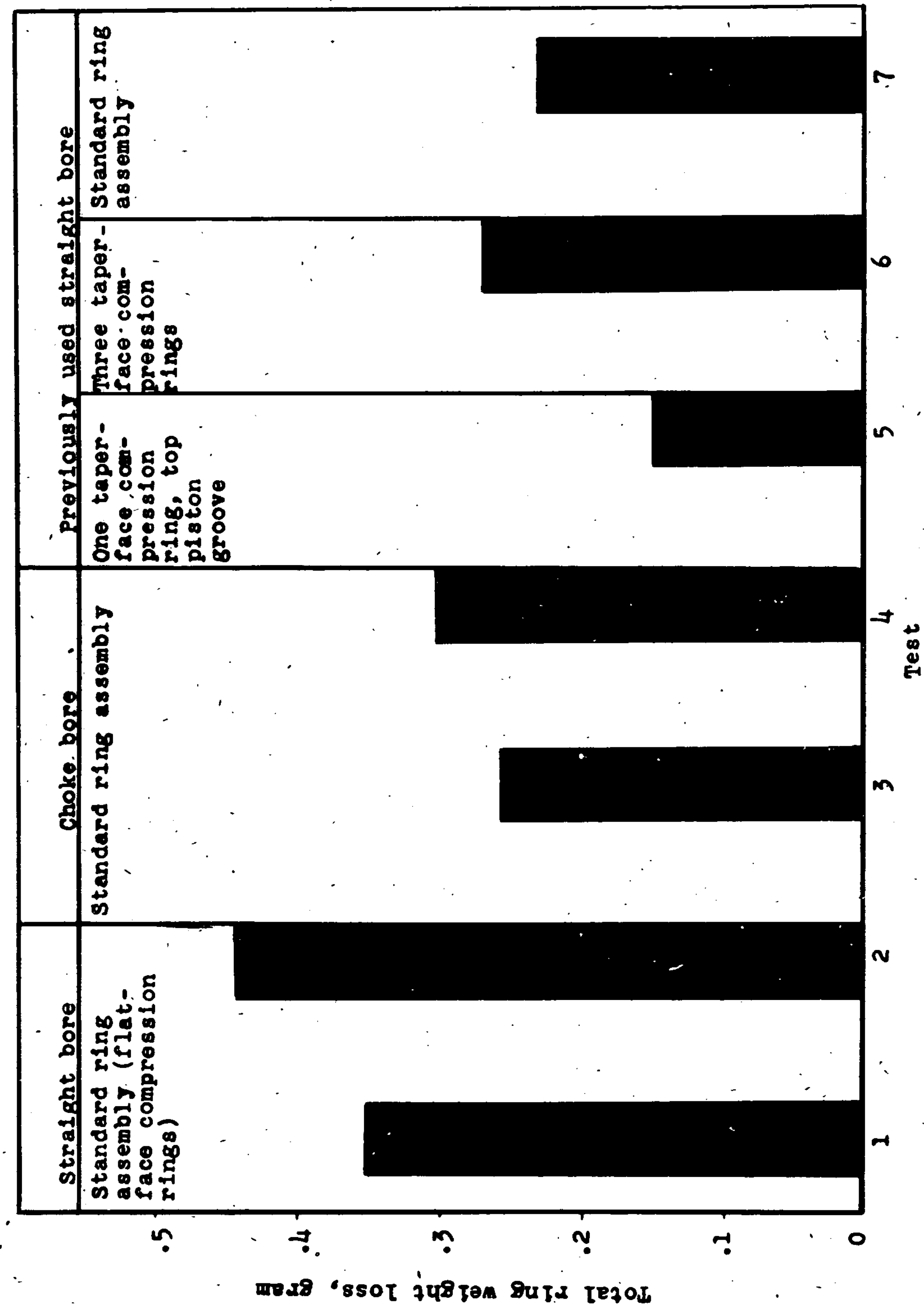


Figure 6. - Total weight loss for all rings in oil-control tests of porous chrome-plated cylinder barrels.

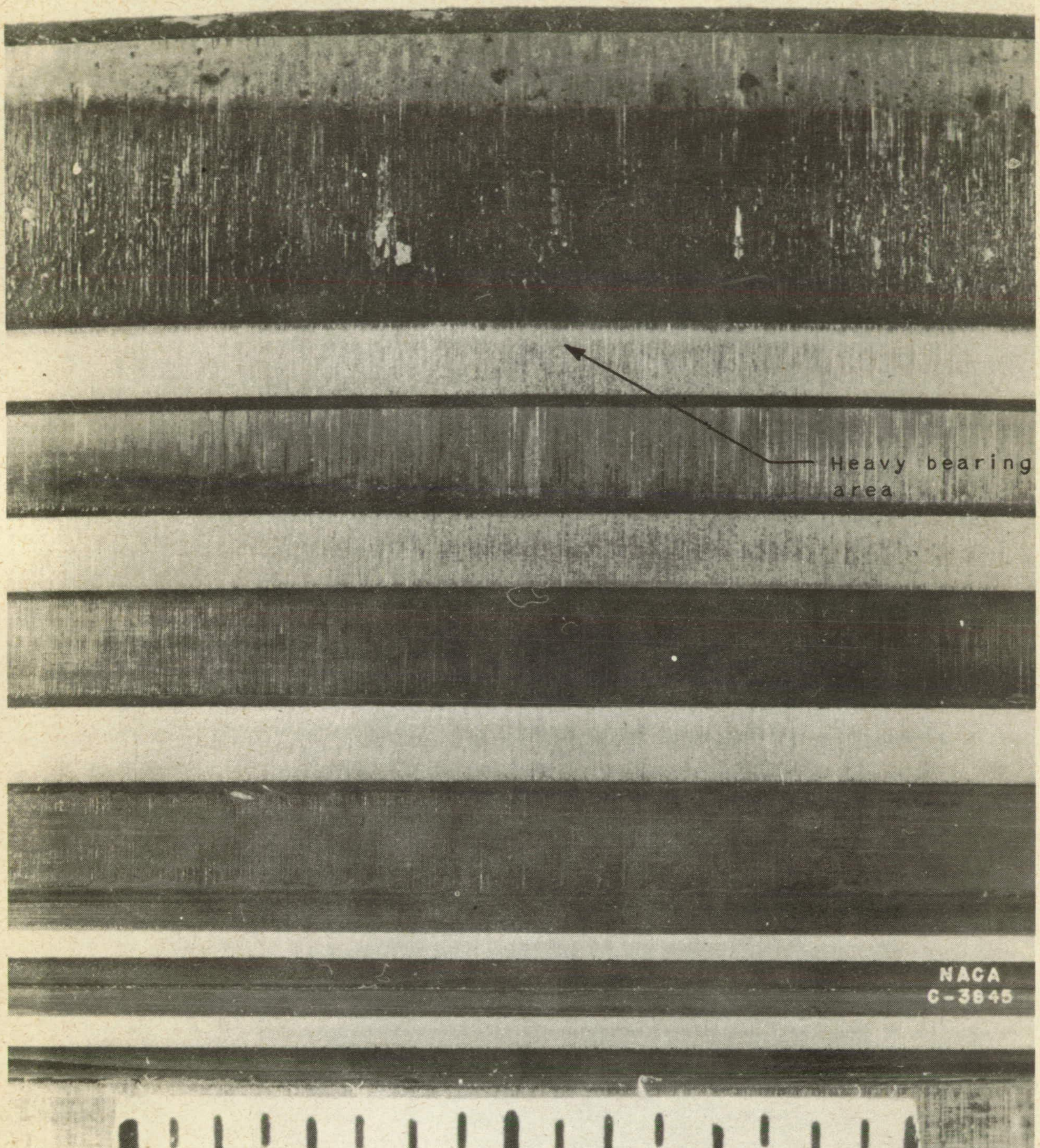


Figure 7. - Condition of surface of top five compression rings, $180^{\circ}$ from gaps, top ring showing heavy bearing area at top of ring, after operation in choke-bore porous chrome-plated cylinder barrel after test 3. X5.

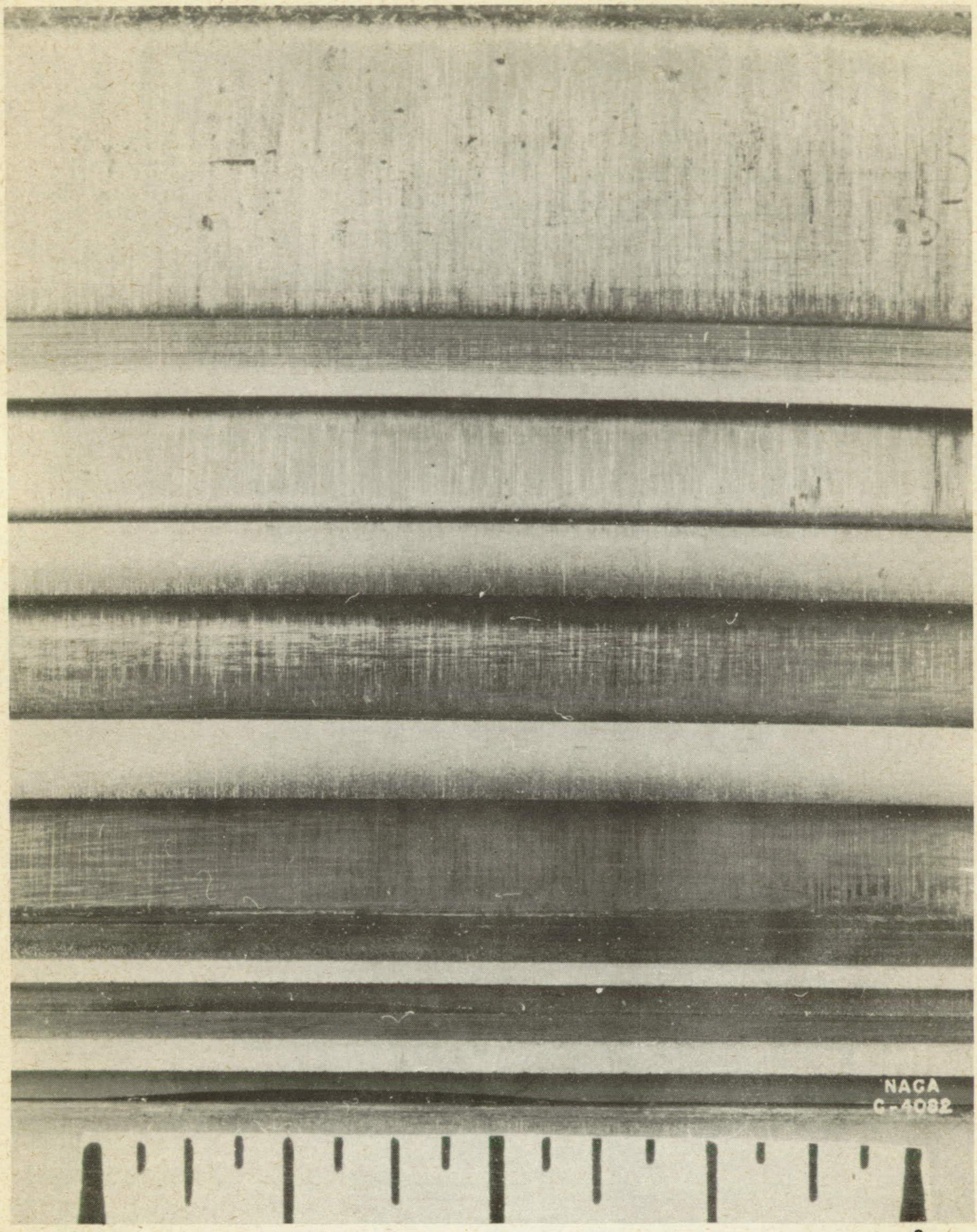


Figure 8. - Condition of surface of top five rings, 180° from gaps, after operation in previously used straight-bore porous chrome-plated cylinder barrel after test 5. The top ring has a 1° taper face; the other rings are flat-face standard parts. X5.

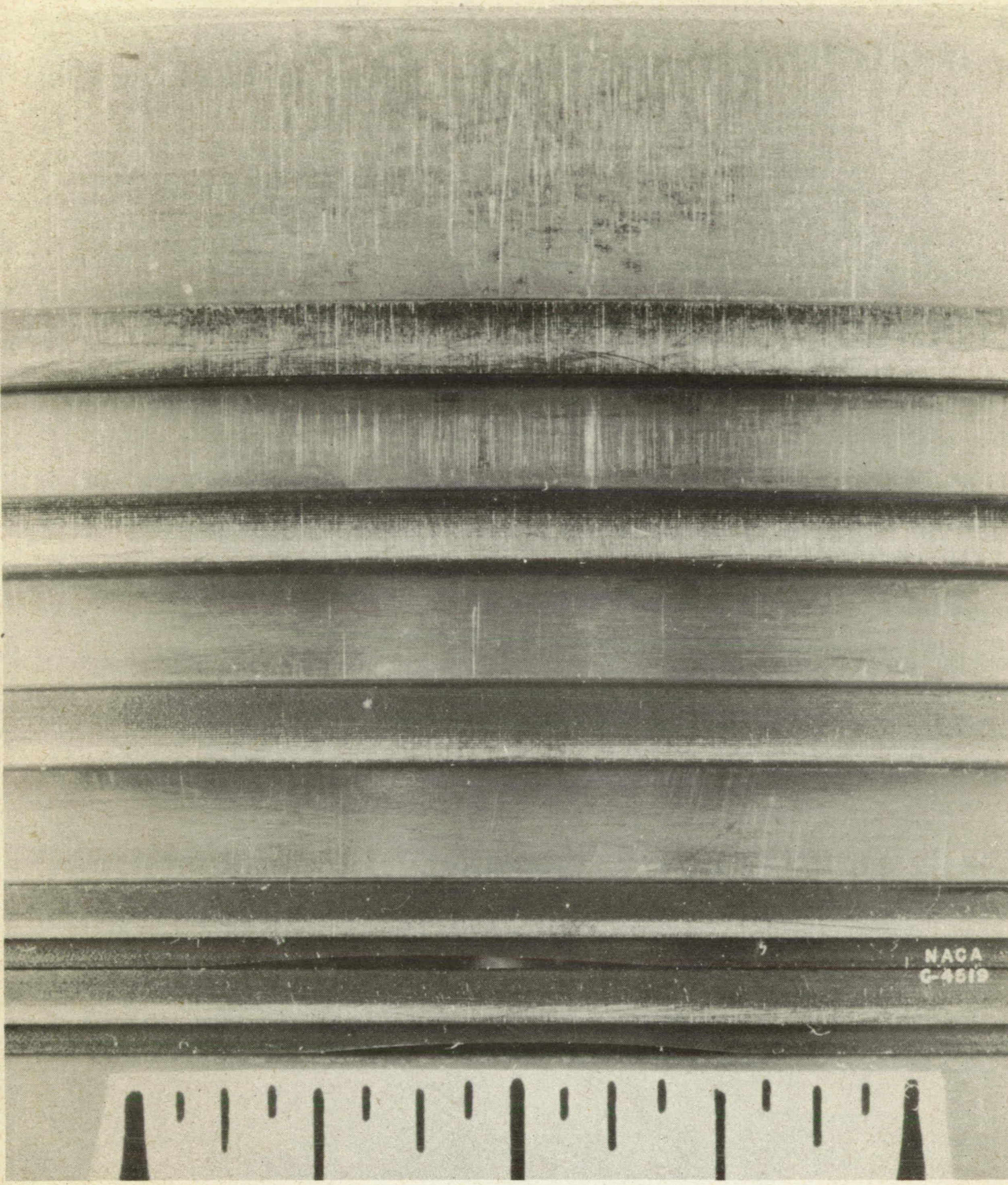


Figure 9. - Condition of surface of the top five piston rings, 180° from gaps, after operation in previously used straight-bore porous chrome-plated cylinder barrel with 1° taper-face compression rings after test 6. X5.

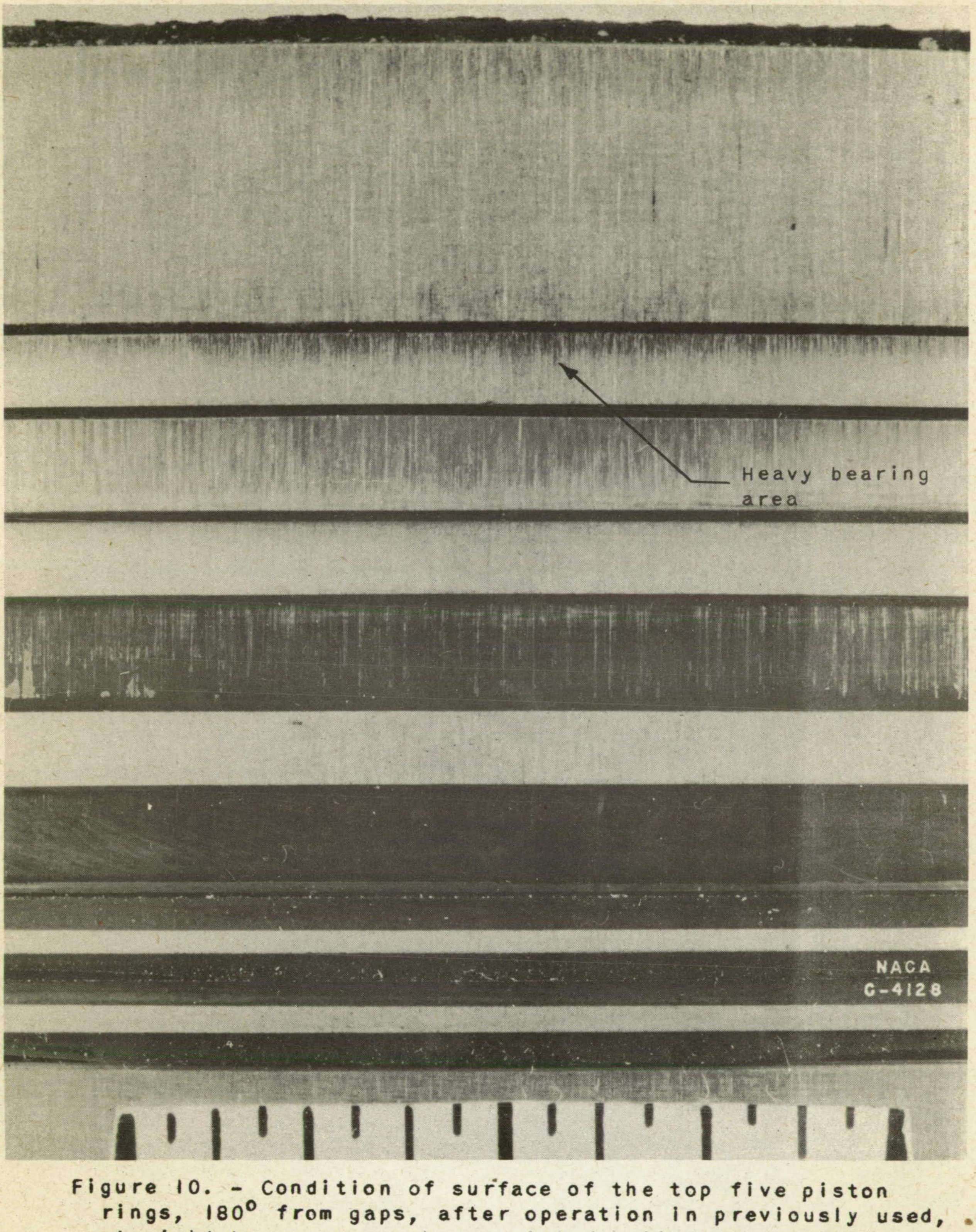


Figure 10. - Condition of surface of the top five piston rings, 180$^{o}$ from gaps, after operation in previously used, straight-bore porous chrome-plated cylinder barrel with standard ring assembly after test 7. X5.


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Figure 11. - Condition of major-thrust face of piston operated in straight-bore porous chrome-plated cylinder barrel after test 1.

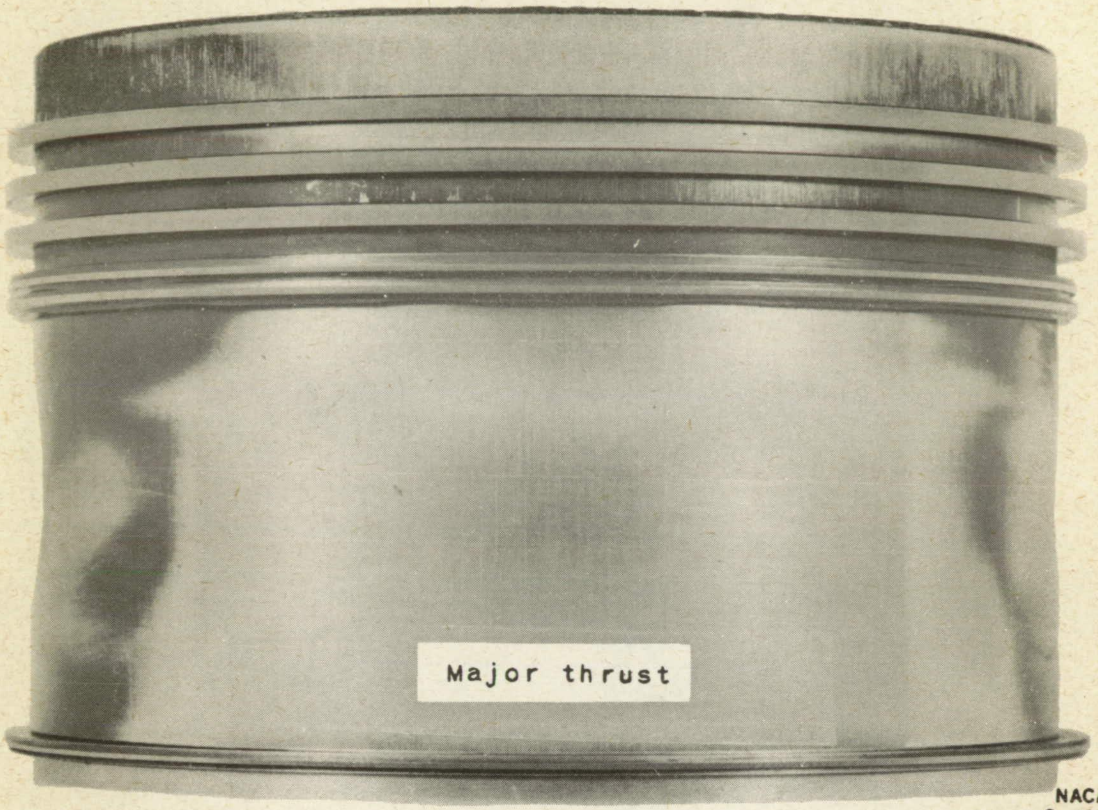



Figure 12. - Condition of major-thrust face of piston operated in previously used porous chrome-plated straight-bore cylinder barrel after test 7.

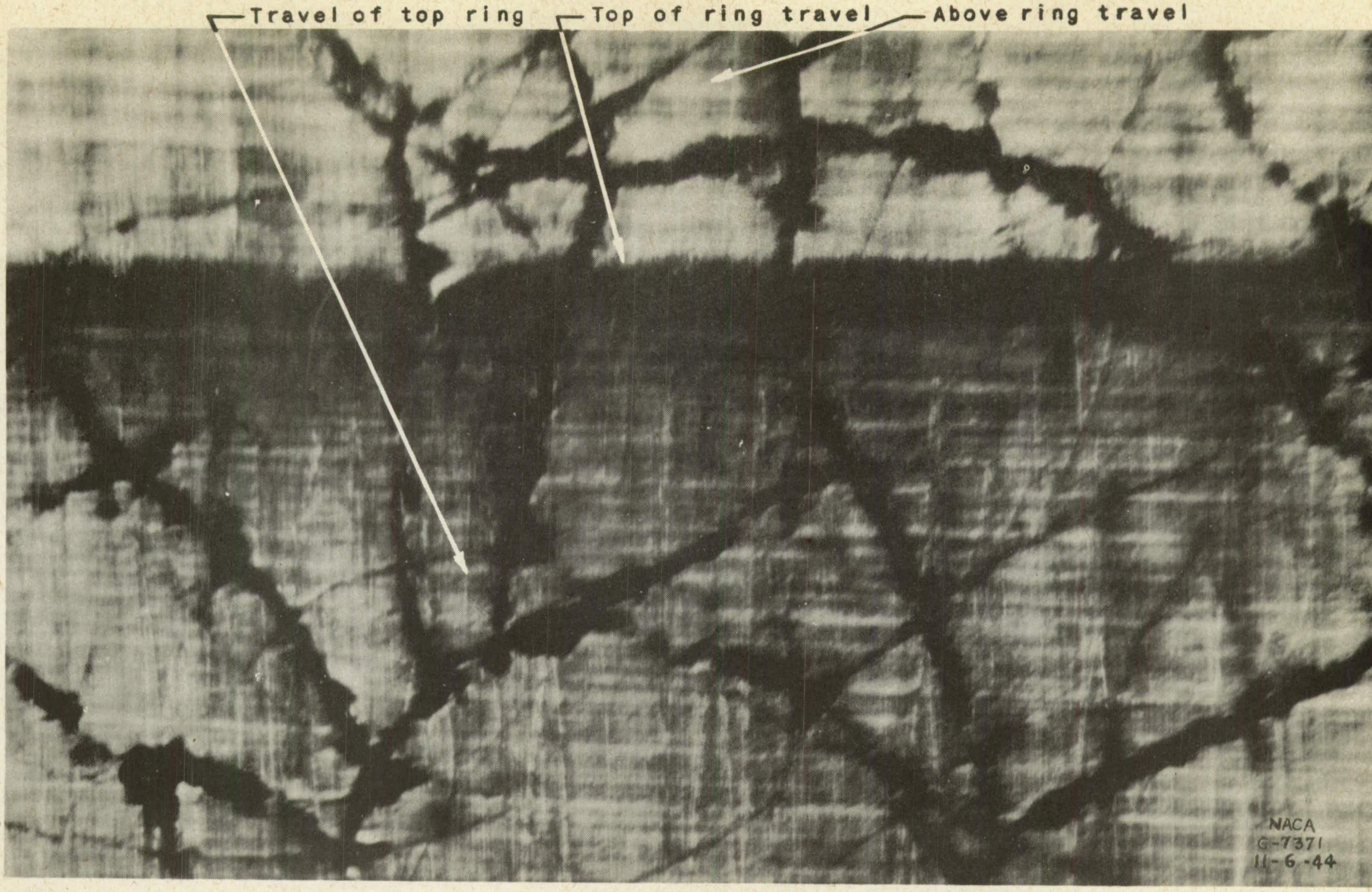
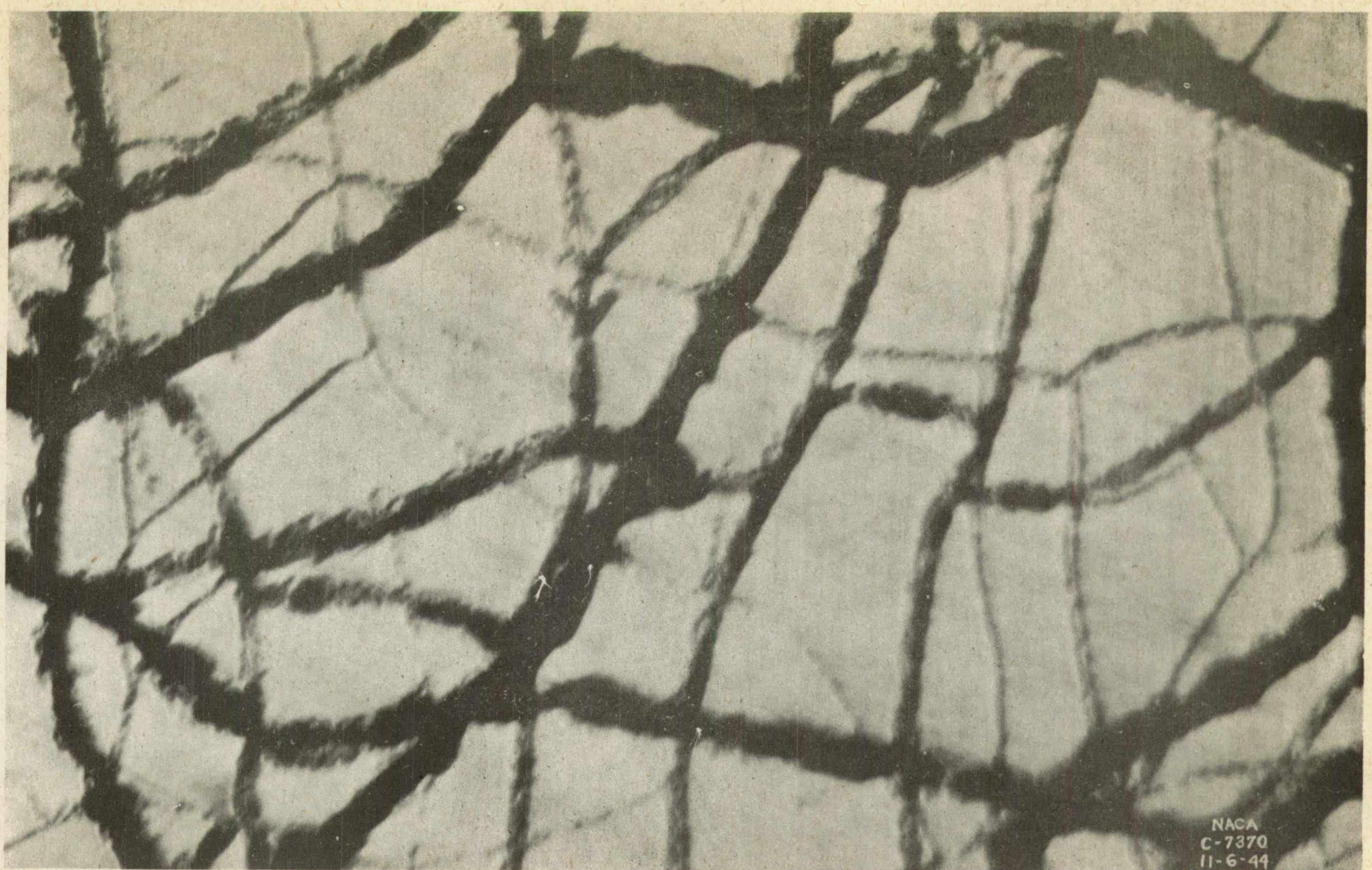
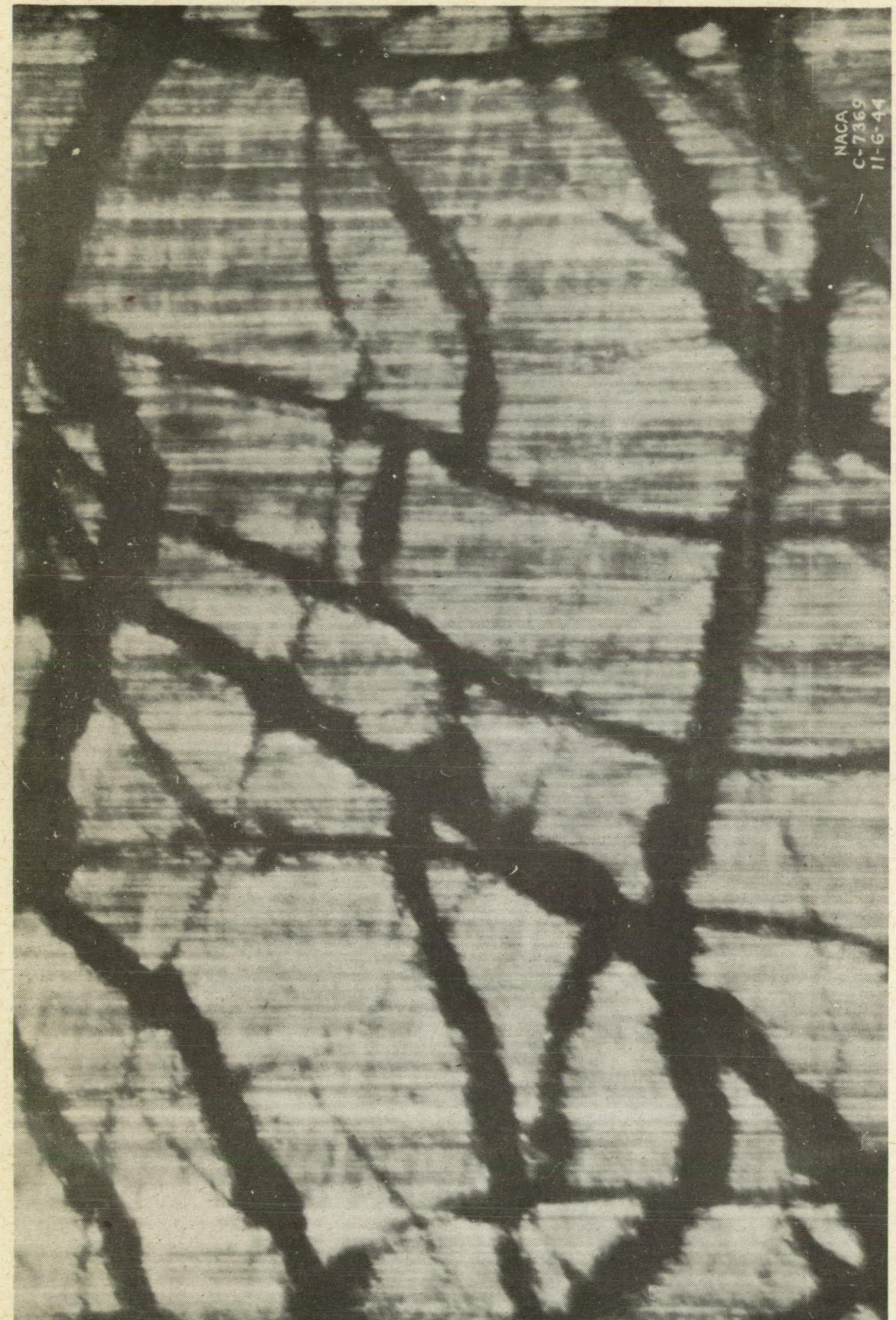



Figure 13. - Photomicrograph of condition of choke-bore porous chrome-plated cylinder barrel showing wear at ring step at top of ring travel, major-thrust face of cylinder bore after test 4. Estimated porosity, 20 percent. X108.




(a) Before test 4.

Figure 14. - Photomicrograph of choke-bore porous chrome-plated cylinder barrel at middle of top-ring travel, major-thrust face. This area is representative of chrome-plating in all cylinders tested. Estimated porosity, 35 percent. X108.




(b) After test 4.

Figure 14. - Photomicrograph of choke-bore porous chrome-plated cylinder barrel at middle of top-ring travel, major-thrust face. This area is representative of chrome-plating in all cylinders tested. Estimated porosity, 35 percent. X108.

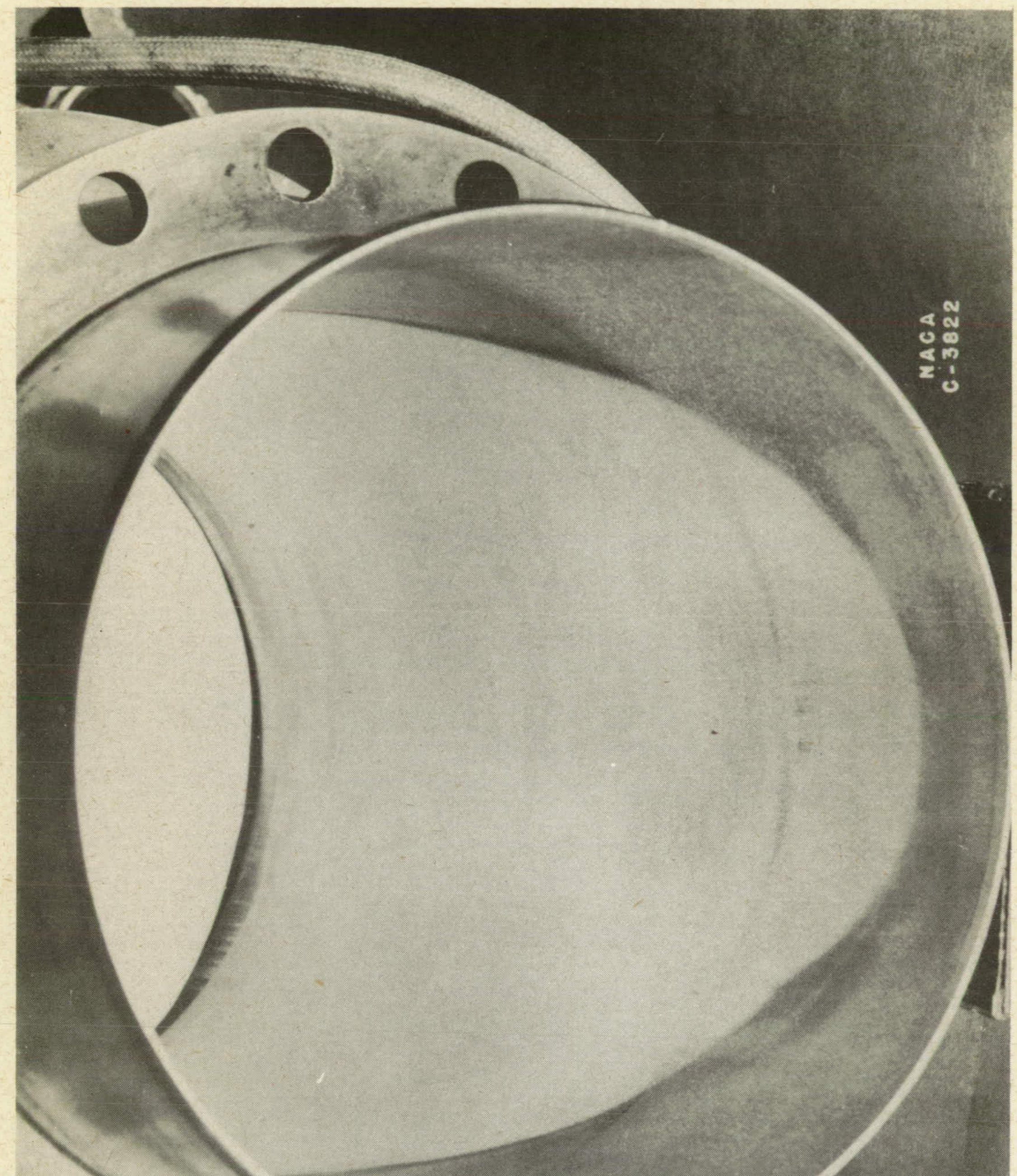



Figure 15. - Condition of major-thrust face of straight-bore porous chrome-plated cylinder barrel after test 1. This condition is representative of condition of bore surfaces after all tests.